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(54) Bearings

(57) An oil impregnated sintered porous metal bearing in the form of a hollow cylinder having a bearing surface comprising the internal cylindrical surface of the bearing is produced from a metal powder by compacting, sintering, coining and oil impregnating. The bearing surface of the bearing comprises a plurality of alternating troughs and ridges (see Figs. 6, 7A, 7B) circumferentially spaced around the bearing surface and is impressed in the bearing surface by corresponding troughs and ridges either on the coining tools or on the forming tools only.

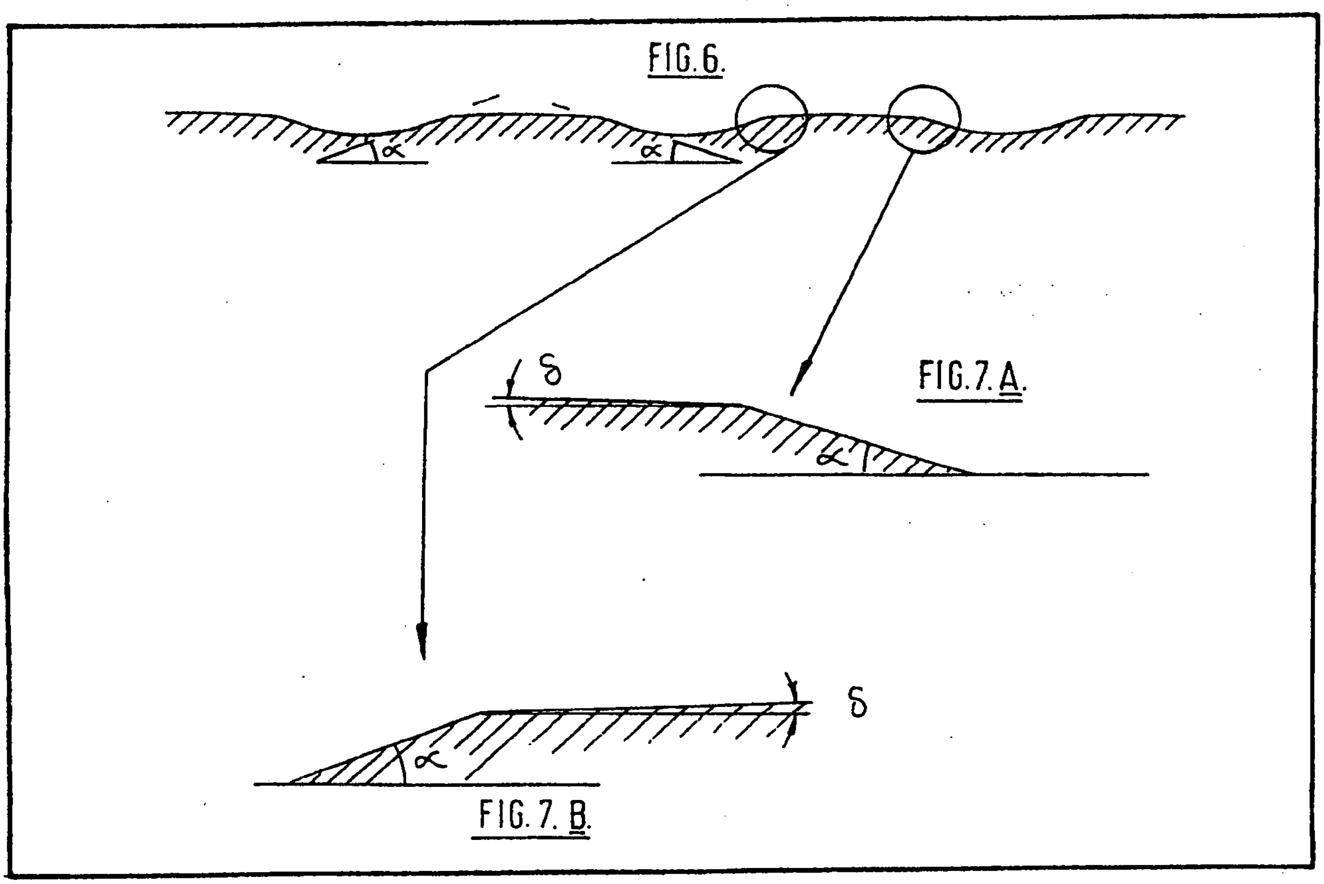

FIG. 6.

FIG. 7. A.

FIG. 7. B.

The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

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FIG.1.

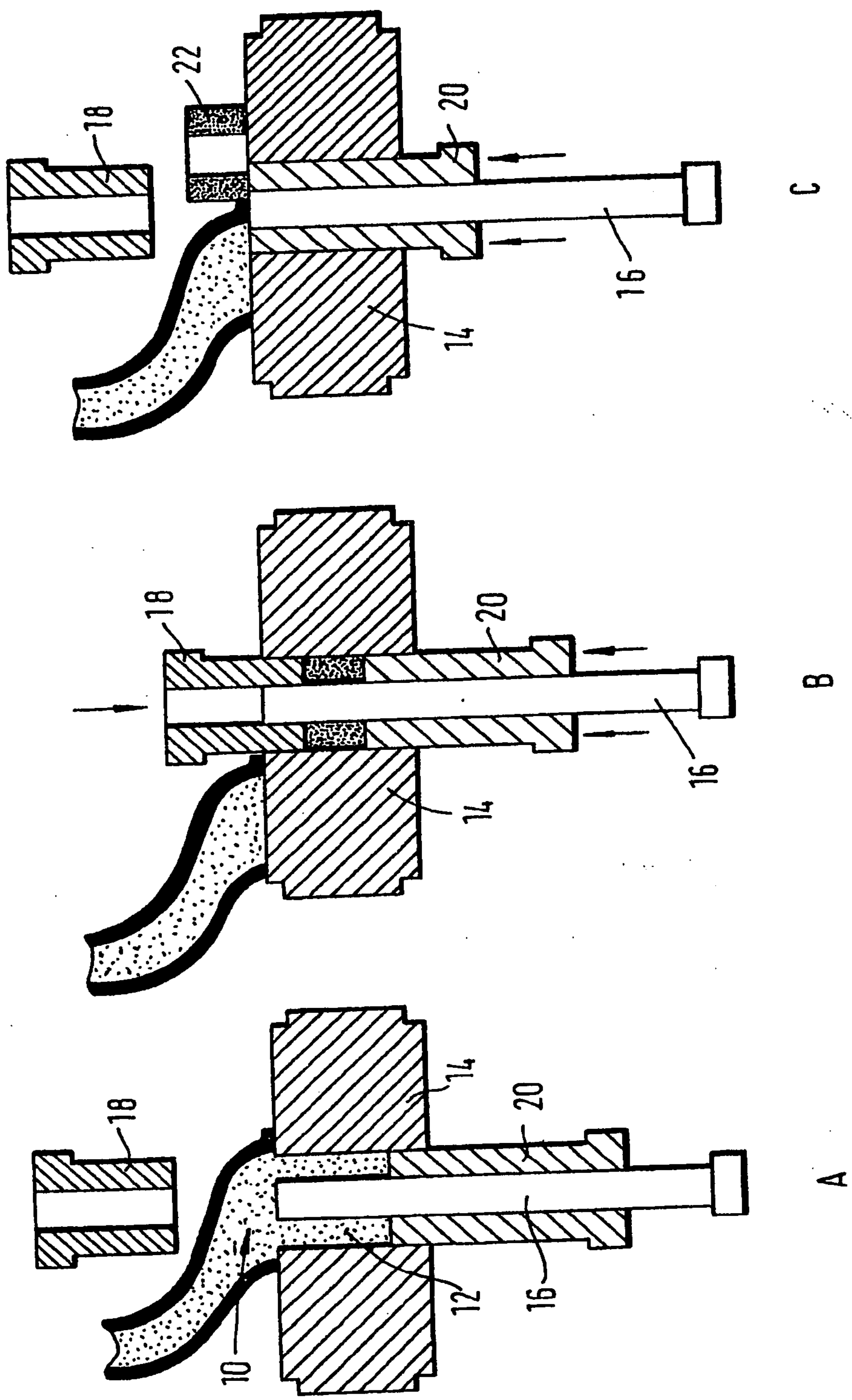


FIG. 4.

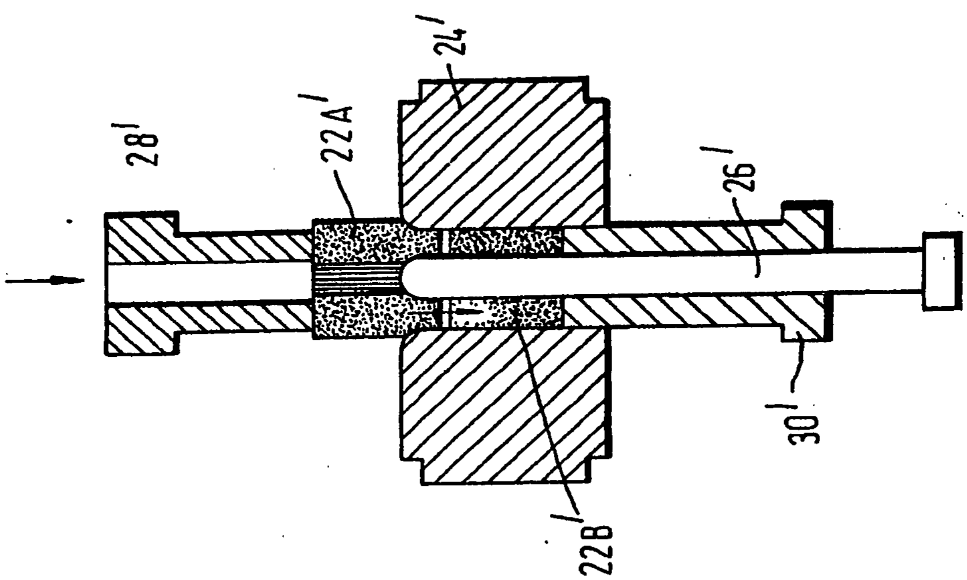
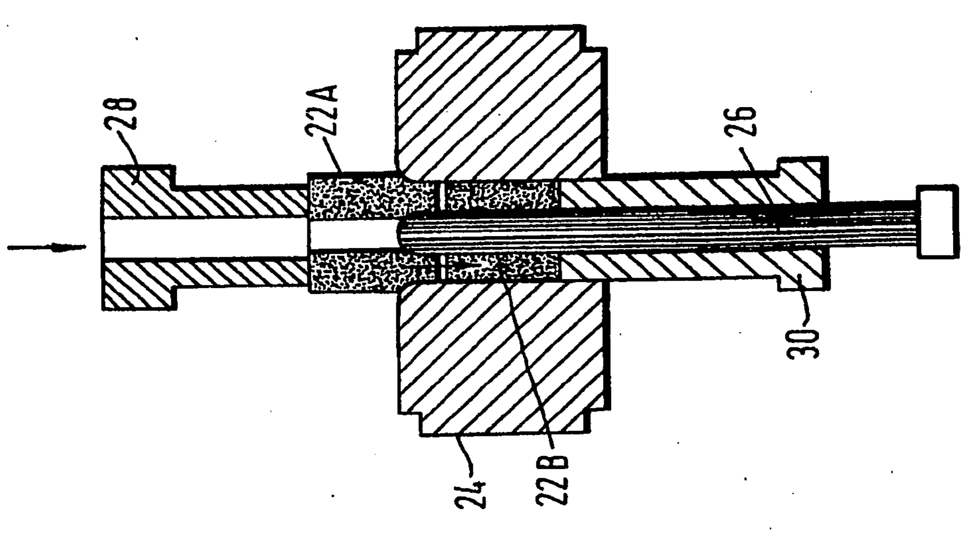


FIG. 2.



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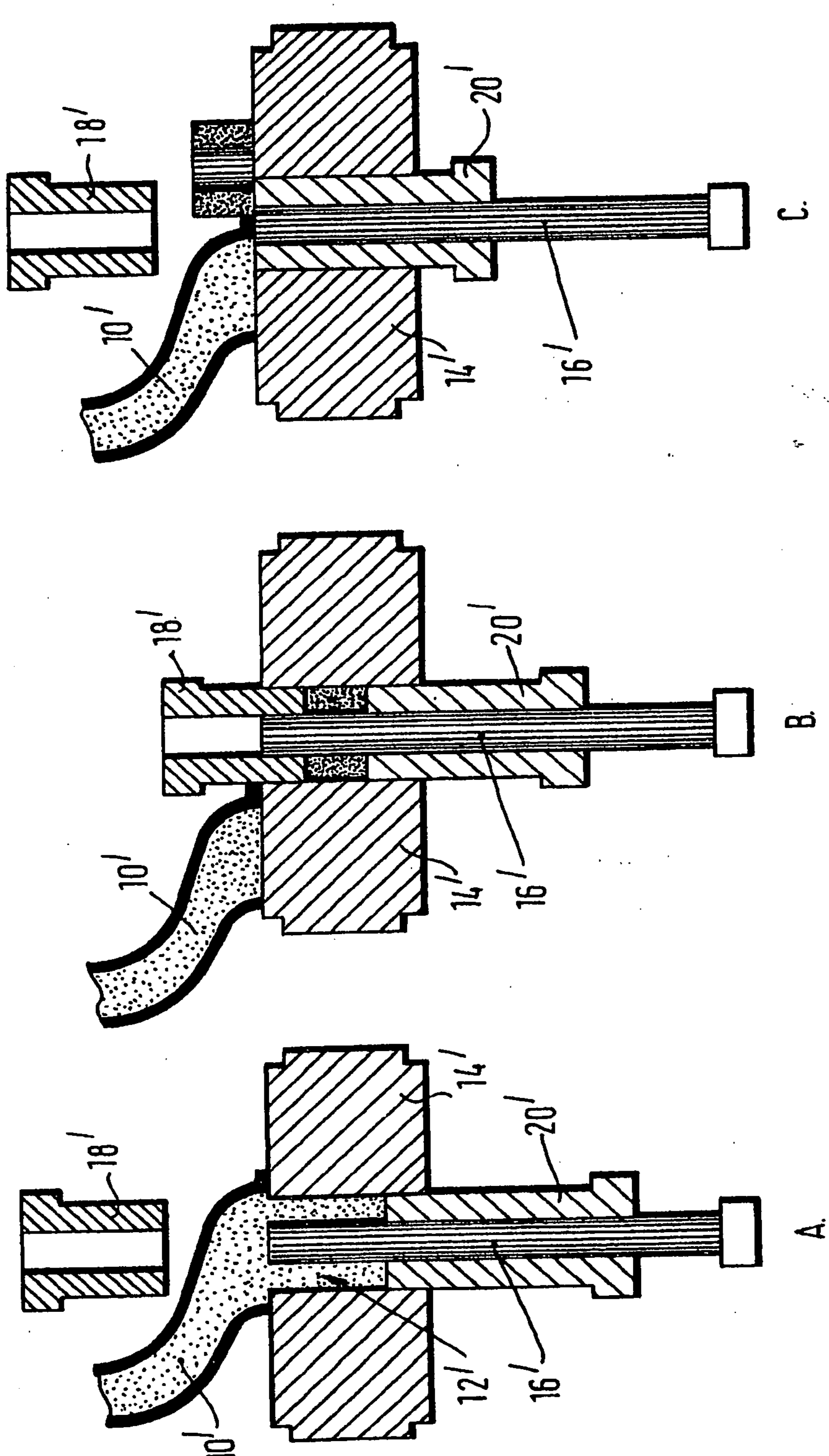

FIG. 3.

FIG. 5.

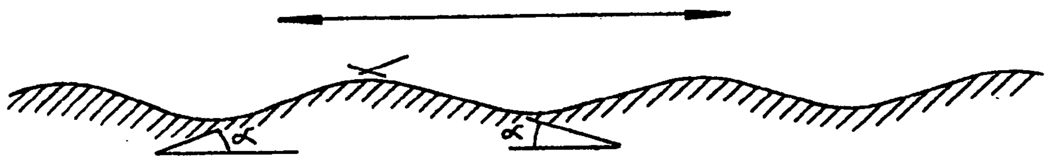

FIG. 6.

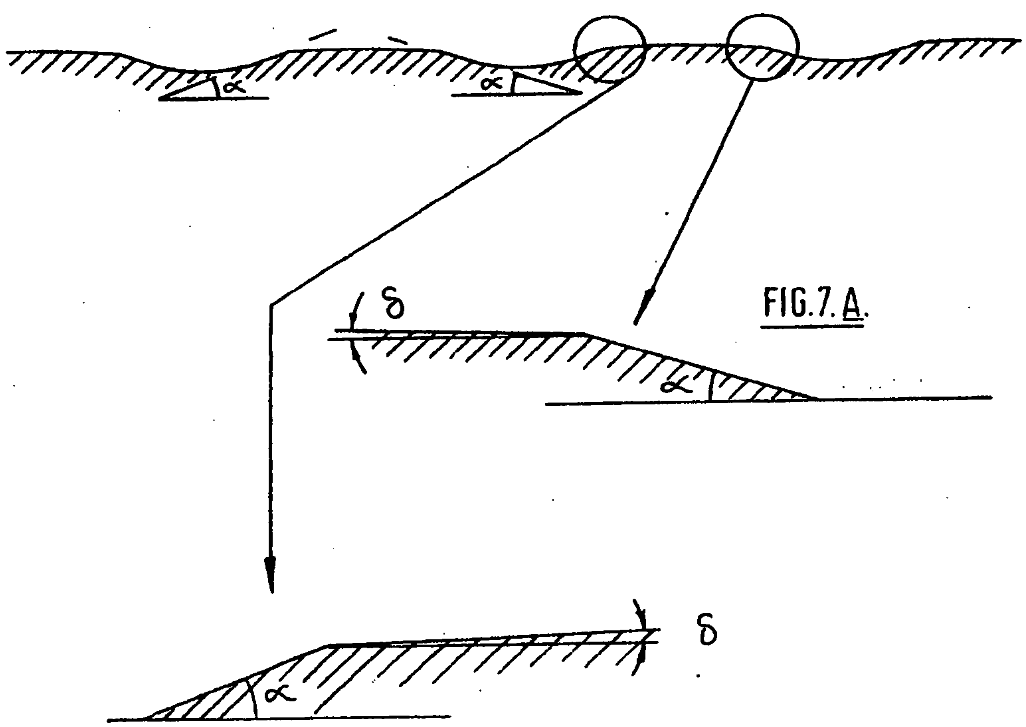

FIG. 7. A.

FIG. 7. B.

FIG. 8.

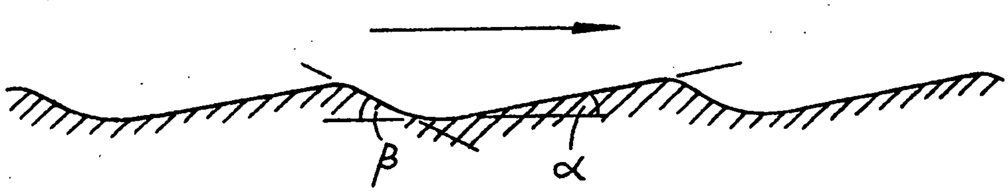

FIG. 9.

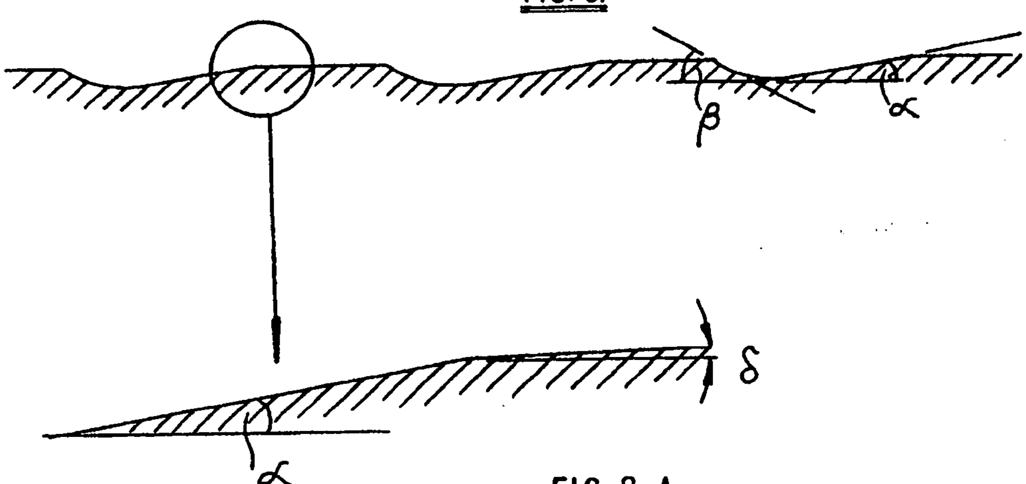

FIG. 9. A.

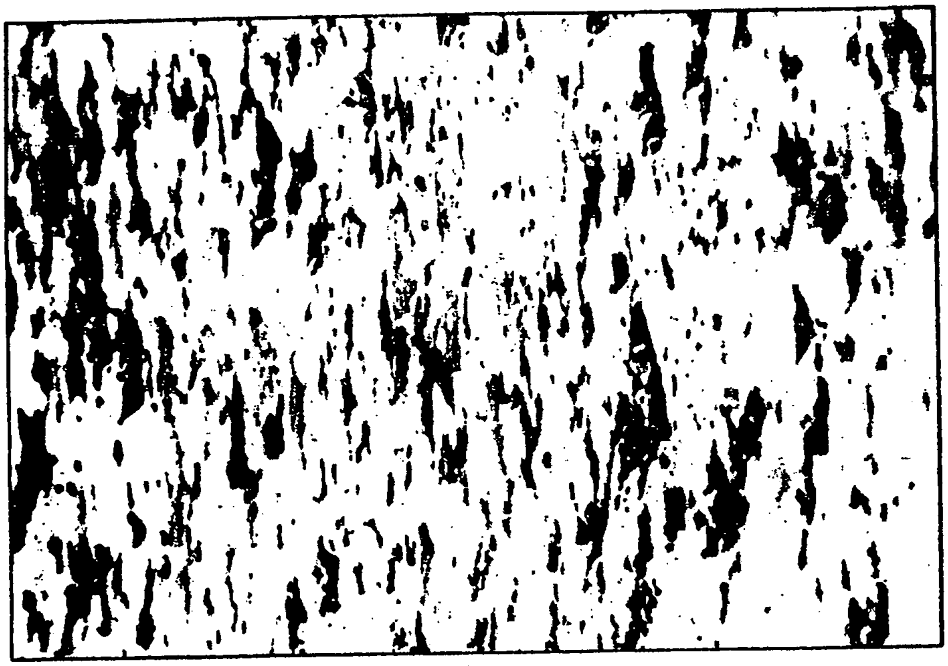

FIG. 11.

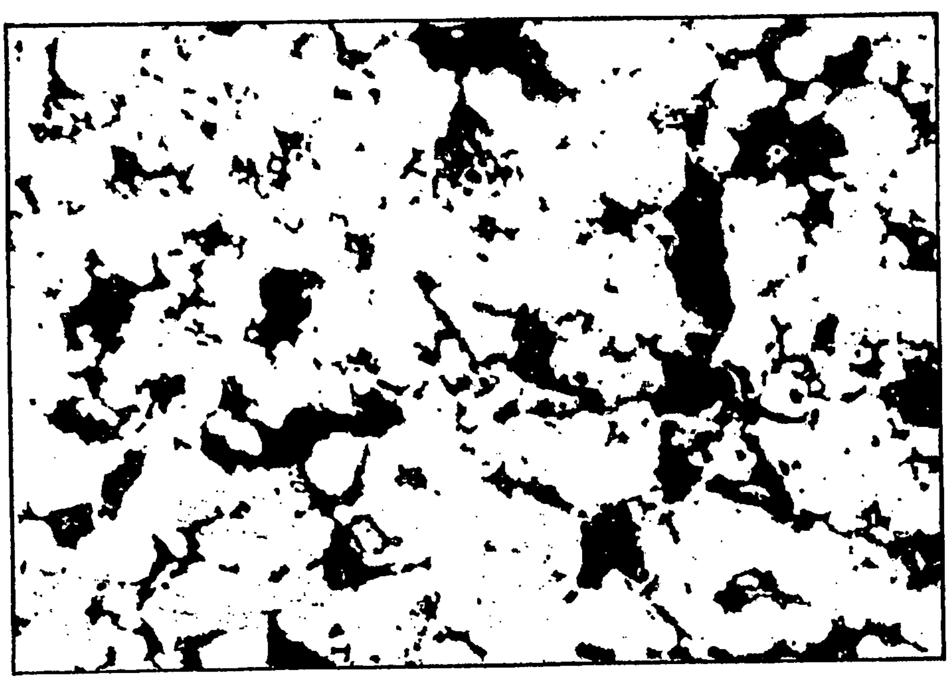

FIG. 10.

FIG. 13.

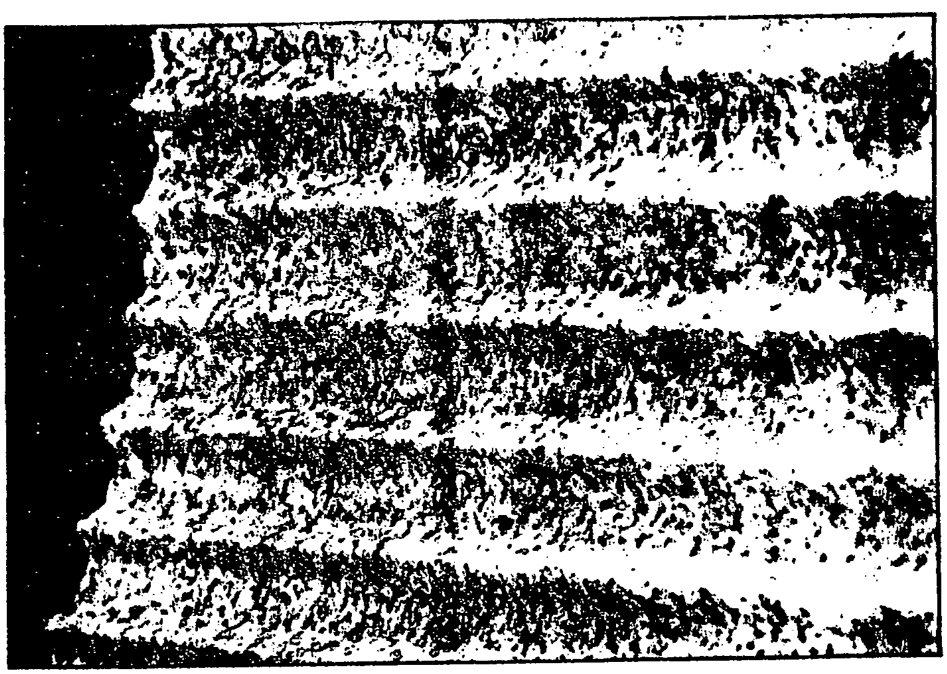

FIG. 12

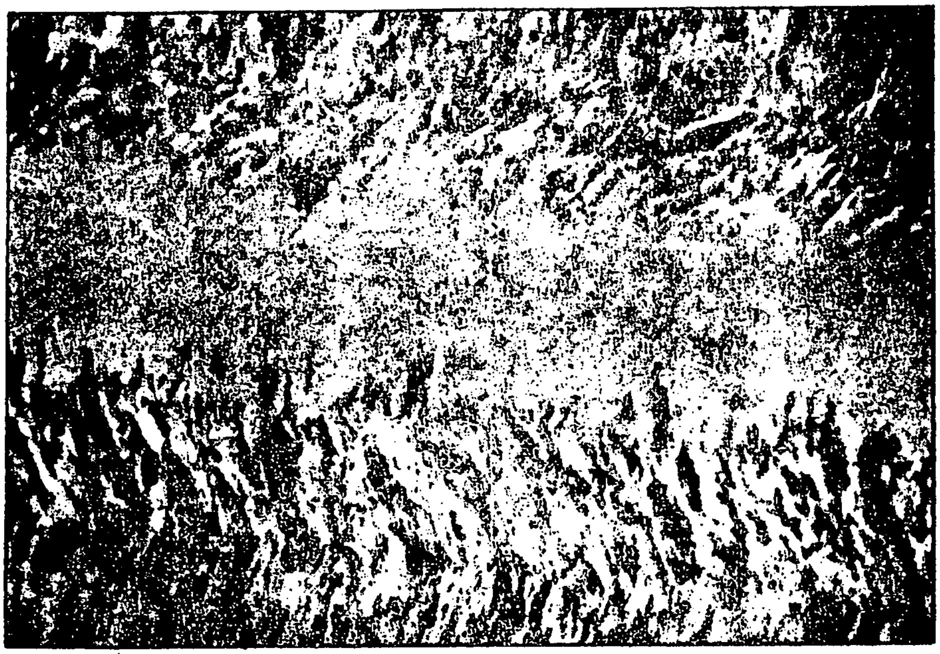

FIG. 15.

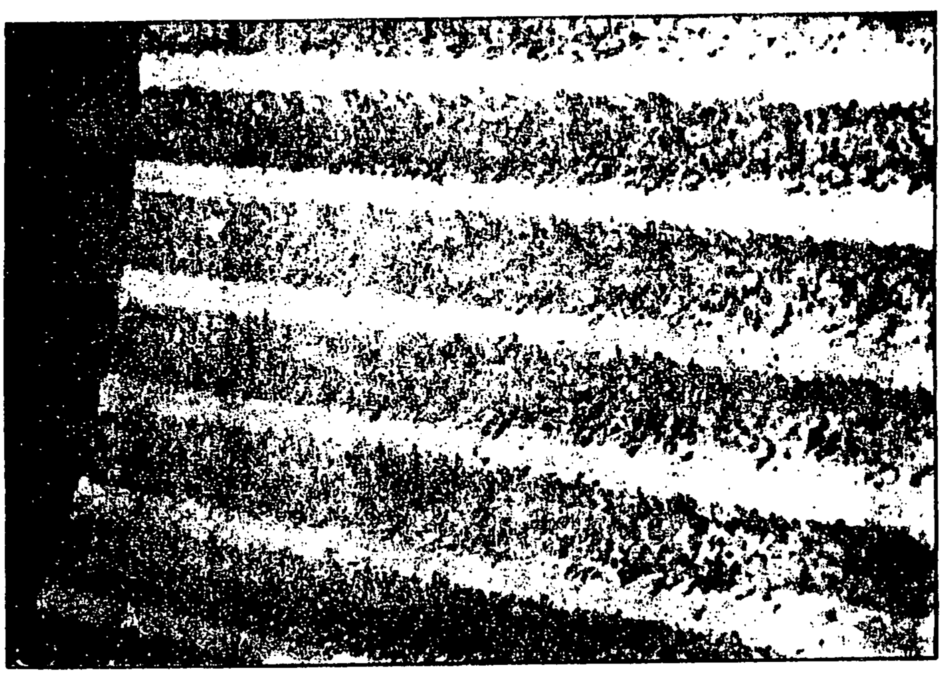

FIG. 14.

FIG. 16.

SPECIFICATION
Porous Metal Bearings

This invention relates to sintered porous bearings. The manufacture of such bearings is well known in the art and generally comprises the steps of cold compacting a metal powder, or mixture of metal powders, in a die; sintering the green compact in a reducing atmosphere and then cold sizing or coining the sintered product to its required final dimensions. Although the degree of compaction may vary, the final product may typically comprise three-quarters metal and one-quarter voids and the final step consists of impregnating the bearing with oil so that the voids become filled with oil. The final product therefore comprises an oil impregnated sintered porous metal bearing which will have a long service life without need of additional lubrication.

It is believed that, during rotation of a journal within a bearing of the type described above, the sintered metal particles forming the bearing surface act as a random collection of micro-thrust pads or lands each of which permits hydro-dynamic lubrication to occur between the land and the journal. It will be appreciated that such lands are of uncontrolled shape and of random distribution and that if one could control the shape and distribution then one could effectively modify the hydro-dynamic lubrication characteristics of the bearing as a whole.

Furthermore it is believed that, in a porous metal bearing, the load carrying lands are lubricated from a dam of oil which forms upstream of the lands. Depending upon the shape of the land some of the oil in the dam flows away between adjacent lands. This effect could be reduced if the lands were not equiaxed but were elongated at right angles to the direction of motion of the journal.

It is an object of the present invention to provide a new or improved sintered porous metal bearing, and methods of manufacturing such a bearing, wherein the bearing surfaces of the bearing provide improved lubrication characteristics in use.

In accordance with the broadest aspect of the invention there is provided an oil impregnated sintered porous metal bearing having a bearing surface comprising a plurality of alternating troughs and ridges circumferentially spaced around the bearing surface and extending parallel to one another and to the longitudinal axis of the bearing. Said alternating troughs and ridges preferably provide a bearing surface to the bearing which is of generally sinusoidal cross-sectional configuration and it is preferred that the frequency of the troughs and ridges is such that there are at least 25 ridges in the circumference of the bearing surface.

The term "generally sinusoidal" as used to describe the cross-sectional configuration of the alternating troughs and ridges will be understood to mean not only a pure sine wave configuration but also any symmetrical or asymmetrical alternating trough and ridge configuration such as, for example, a configuration wherein the peaks of the ridges are flattened. Indeed it may be preferred to provide such a "flat topped" shape of ridge having tapering sides into the adjacent troughs so that the flat top to each ridge constitutes a load bearing land and the tapering sides thereto provide the "ramps" necessary for hydro-dynamic lubrication of the lands during rotation of a journal within the bearing.

The bearing surface of the bearing would generally comprise an inner cylindrical surface and, if the trough and ridge configurations are all symmetrical, then the bearing will accommodate multi-directional rotation of a journal therein. However, it may be desired to form the bearing surface to accommodate uni-directional rotation of a journal in which case the trough and ridge configuration will not be symmetrical. In such a uni-directional bearing it may be convenient to form each ridge with a flat top land and a shallow angle taper ramp from one end of each land into an adjacent trough. The other end of each land also having a tapered side into an adjacent trough but at a much steeper angle from the land. The shallow angle ramp would be the leading side of the ridge having regard to the relative movement which occurs between the bearing and journal, and the steeper side would be the trailing side. In such a uni-directional bearing it will be possible to accommodate more troughs and ridges per unit length of circumference of the bearing surface than is the case with a symmetrical sinusoidal trough and ridge configuration.

In accordance with a further aspect of the invention there is provided a method of manufacturing an oil impregnated sintered porous metal bearing having a bearing surface comprising a plurality of alternating troughs and ridges circumferentially spaced around the bearing surface and extending parallel to one another and to the longitudinal axis of the bearing comprising the steps of forming a green compact of metal powders in forming tools; sintering the green compact by heating it in an atmosphere which is reducing to the oxides of the metal powders; compressing the resulting sintered compact in coining tools to produce a coined bearing of the required final dimensions and impregnating the resulting porous bearing with a lubricating oil characterised in that the said alternating troughs and ridges are formed subsequent to the sintering of the compact. The troughs and ridges may be formed by corresponding ridges and troughs on the coiling tools, or by a further operation subsequent to the coining operation.

Also in accordance with the invention there is provided an alternative method of manufacturing an oil impregnated sintered porous metal bearing having a bearing surface comprising a plurality of alternating troughs and ridges circumferentially spaced around the bearing surface and extending parallel to one another and to the longitudinal axis of the bearing comprising the steps of forming a

green compact of metal powders in forming tools; sintering the green compact by heating it in an atmosphere which is reducing to the oxides of the metal powders; compressing the resulting sintered compact in coining tools to produce a coiled bearing of the required final dimensions and impregnating the resulting porous bearing with a lubricating oil characterised in that the said alternating troughs and ridges are formed in the green compact by the forming tools. The troughs and ridges may be subsequently reduced in radial depth during compression of the sintered compact in the coining tools.

When producing an oil impregnated sintered porous metal bearing in accordance with the method described in either of the two preceding paragraphs the green compact is formed in forming tools which comprise an outer die having a bore which defines the outer diameter, a core rod which defines the inner diameter and two punches in the form of hollow cylinders which slide between the outer die and the core rod in order to compress the powder contained between the core rod and the die to produce a compact in the form of a hollow cylinder, and to eject the green compact from between the die and the core rod. Similarly the coining tools will comprise a die which defines the outer diameter of the bearing, a core rod which defines the inner diameter and two punches in the form of hollow cylinders which slide between the die and the core rod in order to press the sintered compact between the die and the core rod to produce the coined porous bearing of the required final dimensions, and to eject the bearing from between the die and the core rod.

In a bearing according to the invention having a bearing surface comprising the inner cylindrical surface, the said alternating troughs and ridges which are circumferentially spaced around the bearing surface will be produced either by providing alternating troughs and ridges on the core rod of the coining tools only or by providing alternating troughs and ridges on the core rod of the forming tools (with a smooth surfaced core rod in the coining tools). In certain circumstances a combination of both techniques might be utilised, i.e. by having the core rod of both the forming and coining tools provided with troughs and ridges. It has been found that, in porous metal bearings produced in accordance with the invention, the lands at the top of the ridges are elongated in the direction of the troughs and ridges i.e. at right angles to the direction of motion of the journal. Hence the improved performance of these bearings with troughs and ridges is enhanced by the elongation of the lands, or the joining together of adjacent lands, at the tops of the ridges whereby the leakage of oil from the oil dams around the lands is reduced.

Other features of the invention will become apparent from the following description given herein solely by way of example with reference to the accompanying drawings wherein:—

Figures 1A, 1B, 1C are diagrammatic side cross-sectional views of forming tools for producing a green compact of a porous metal bearing in accordance with the invention,

Figure 2 is a diagrammatic side cross-sectional view of coining tools for sizing the compact after it has been sintered; the difference in outer and inner diameter of the compact before and after sizing being exaggerated for the purposes of illustration,

Figures 3A, 3B, 3C are diagrammatic side cross-sectional views similar to Figures 1A to 1C but showing alternative forming tools for producing a green compact,

Figure 4 is a diagrammatic side cross-sectional view of coining tools for sizing the compact of Figure 3 after it has been sintered; the difference in outer and inner diameters of the compact before and after sizing being exaggerated for the purposes of illustration,

Figure 5 is a generated side view of the profile of a multidirectional porous metal bearing in accordance with the invention, after sintering but before sizing, as may be produced by the tooling of Figure 3,

Figure 6 is a similar view to that of Figure 5 but taken after sizing,

Figures 7A and 7B are enlarged views of the ringed portions of Figure 6,

Figure 8 is a generated side view of the profile of a unidirectional porous metal bearing in accordance with the invention, after sintering but before sizing as may be produced by the tooling of Figure 3,

Figure 9 is a similar view to that of Figure 8 taken after sizing,

Figure 9A is an enlarged view of the ringed portion of Figure 9,

Figure 10 is a photograph to a magnification of ×200 of a typical prior art porous metal bearing surface,

Figure 11 is another photograph to a magnification of ×200 of the bearing surface shown in Figure 10 but taken at a 15° glancing angle to the surface,

Figure 12 is a 15° glancing angle photograph to a magnification of ×30 of a bearing surface in accordance with the invention, after sintering but before sizing, as may be produced by the tooling of Figure 3,

Figure 13 is a similar photgraph to that shown in Figure 12 but to a magnification of ×200,

Figure 14 is another similar photograph to that of Figure 12, again to a magnification of ×30, but showing the bearing surface after sizing,

Figure 15 is a similar photograph to that of Figure 14 but to a magnification of ×200, and

Figure 16 is another 15° glancing angle photograph, to a magnification of ×120, of another bearing surface in accordance with the invention after sizing to produce more nearly equal proportions of trough and land width.

Referring to Figures 1 and 2, an oil impregnated sintered porous metal bearing in accordance with the invention is made from powdered metal or a mixture of powdered metals. For example iron, copper, copper-tin or some steel alloy powders may be utilised. To produce a bearing in the form of a hollow cylinder having its bearing surface comprising the inner cylindrical surface of the bearing, a metered quantity of metal powder 10 is fed to the die cavity 12 of forming tools which comprise an outer die 14 having a bore which defines the outer diameter of the green compact, a smooth surfaced core rod 16 which defines the inner diameter and two punches in the form of hollow cylinders 18 and 20 which slide between the outer die 14 and the core rod 16 in order to compress the powder contained in the die cavity 12 to produce a green compact 22 in the form of a hollow cylinder. The steps of powder metering and compaction are shown in Figures 1A and 1B.

The green compact 22 is then ejected from the forming tools (see Figure 1C) and at this stage said compact is self sustaining but is of low physical strength and could for example be easily crushed between one's fingers. In order to impart greater physical strength to the compact it is then sintered by heating it in an atmosphere which is reducing towards the oxides of the metal powders and at a temperature which is insufficient to melt the compact but which is sufficient to cause the metal powder particles to weld together sufficiently to increase the strength of the compact to that required by the bearing in its intended use.

After the sintering stage the sintered compact 22A (see Figure 2) is then fed to coining tools which compress the sintered compact into a bearing of the required final dimensions. The coiling tools are similar to the forming tools in that they comprise a die 24 which defines the outer diameter of the bearing, a core rod 26 which defines the inner diameter and two punches 28 and 30 in the form of hollow cylinders which slide between the outer die 24 cavity and the core rod in order to press the sintered compact 22A between the die 24 and the core rod 26 to produce a coined porous bearing 22B of the required final dimensions. In this particular method the core rod 26 of the coining tools has an outer surface comprising a plurality of circumferentially alternating troughs and ridges extending parallel to one another and parallel to the longitudinal axis of the core rod so that, during the coining operation, the sintered compact 22A is provided on its internal cylindrical surface with a corresponding plurality of alternating troughs and ridges circumferentially spaced around such surface and extending parallel to one another and to the longitudinal axis of the bearing.

After the coining operation has been completed the bearing 22B is in its required final dimensional form and comprises generally of the order three-quarters metal and one-quarter voids. Oil is then allowed to enter the voids whereby the bearing becomes oil impregnated and will not generally require additional lubrication during its service life.

An alternative and preferred, method of producing such a bearing in accordance with the invention will now be described with reference to Figures 3 and 4 wherein like reference numerals, but primed, refer to like part already described with reference to Figures 1 and 2. In this embodiment, a metered quantity of metal powder 10′ is fed to the die cavity 12′ of forming tools which comprise an outer die 14′ having a bore which defines the outer diameter of the green compact, a core rod 16′ which defines the inner diameter and two punches in the form of hollow cylinders 18′ and 20′ which slide between the outer die 14′ and the core rod 16′ in order to compress the powder contained in the die cavity 12′ to produce a green compact 22′ in the form of a hollow cylinder. The steps of powder metering and compaction are shown in Figures 3A and 3B. The core rod 16′ is provided with an outer surface comprising a plurality of circumferentially alternating troughs and ridges extending parallel to one another and parallel to the longitudinal axis of the core rod so that the green compact 22′ is provided on its internal cylindrical surface with a corresponding plurality of alternating troughs and ridges circumferentially spaced around such surface and extending parallel to one another and to the longitudinal axis of the green compact.

After compaction, the green compact 22′ is ejected from the forming tools as shown at Figure 3C.

The green compact 22′ is then passed through a sintering furnace in the same manner as previously described with reference to Figures 1 and 2 to produce a sintered compact 22A′ which is then fed to coining tools which compress the sintered compact into a bearing of the required final dimensions. The coining tools are similar to the forming tools in that they comprise a die 24′ which defines the outer diameter of the bearing, a core rod 26′ which defines the inner diameter and two punches 28′ and 30′ in the form of hollow cylinders which slide between the outer die 24′ and the core rod 26′ in order to press the sintered compact 22A′ between the die 24′ and the core rod 26′ to produce a coined porous bearing 22B′ of the required final dimensions. In this method the core rod 26′ of the coining tools is provided with a smooth external surface and, during the coining operation, the originally formed troughs and ridges in the bearing may be compressed radially in which case the radial depth of the troughs produced by the forming tools will be greater than that required in the finished bearing.

In general, the greater is the number of troughs and ridges present the better is the performance, and by way of example it is preferred that the arrangement of alternating troughs and ridges on either the core rods of the forming or coining tools are such that at least 25 alternating troughs and ridges are formed in the bearing surface of the finished bearing.

By way of comparison a porous bronze bearing with troughs and ridges manufactured in accordance with the invention by the method previously described with reference to Figures 3 and 4 was tested against an identically produced bearing but without troughs and ridges therein. Both bearings comprised 10% tin in copper, had a density of 6 gms/cc and were maintained stationary with a journal rotating therein, a load being applied to the centre of the length of the stationary bearing.

Test details were as follows:—

Journal speed	3700 rpm
Oil	Tellus 137
Oil content	20% by volume
Running clearance	30 microns
Bore diameter	19.16 mm
Bearing wall thickness	3 mm
Room temperature	25°C

The porous bearings with troughs and ridges in accordance with the invention were formed with 92 ridges around their circumference, the peak to valley depth of the ridges and troughs being 20 microns.

Test 1

Bearing length	19.1 mm
Load	8.5 kiloponds
	Running temperature of the bearing
Bearing with troughs and ridges	85°
Bearing without troughs and ridges	148°C

Test 2

Bearing length	25.4 mm
Load	5.5 kiloponds
	Running temperature of the bearing
Bearing with troughs and ridges	82°C
Bearing without troughs and ridges	117°C

Test 3

Bearing length	12.95 mm
Load	5.5 kiloponds
	Running temperature of the bearing
Bearing with troughs and ridges	100°C
Bearing without troughs and ridges	139°C

The foregoing tests demonstrate that, for a given load, a porous metal bearing with troughs and ridges produced in accordance with the invention runs with less friction, and hence runs at a lower temperature, than an equivalent porous metal bearing without troughs and ridges. It follows therefore that, for the same friction or running temperature, a bearing produced in accordance with the invention can be run at a higher load than an equivalent bearing without troughs and ridges. Thus sintered metal bearings in accordance with the invention may be utilisable in high load situations where it may normally not be expected that a sintered bearing would be usable at all.

Reference has been made previously to the production of bearings in accordance with the invention which may be either multi-directional or uni-directional. Although the load carrying capacity of a bearing constructed to accomodate multi-directional shaft rotation is generally less than a bearing constructed to accomodate uni-directional shaft rotation, the load carrying capacity may be adequate and in any case superior to a bearing without ridges and troughs constructed at the bearing surface in accordance with the invention.

Figure 5 shows a section through the contoured surface of a typical example of a porous bearing suitable for multi-directional journal rotation. After forming and sintering, such as may be produced by the apparatus and method previously described with reference to Figure 3. It will be appreciated that the curved bearing surface of the bearing has been generated into a straight line to facilitate illustration of the ridges and troughs the tangent of the contoured surface is shown as angle alpha.

Figure 6 shows the same surface as in Figure 5 after the bore of the bearing has been sized by a smooth surfaced core rod in the coining tools, such as for example, the type shown in Figure 4. It should be noted that the tops of the ridges have become flattened by the action of the core rod plastically deforming the porous metal. These flattened lands are the load carrying portions of the bearing surface whilst the unaffected trough portions act as oil reservoirs feeding oil to the surface of these lands.

Figure 7A shows a magnified view of the junction between a land area and the original area after coining whilst Figure 7B shows a similar view to Figure 7A but at the other end of the land, these being symmetrical one to the other but reversed. It may be noted that the angle alpha is almost unchanged by the coining operation.

It should also be noted that in Figures 7A and 7B the top of the land is not flat but subtends a small angle delta. This slight taper arises because the porous metal at the top of the ridges corresponding to the centre of the lands, has been subjected to a greater degree of plastic defomation and greater stress than elsewhere in the contour. Hence the amount of springback (or elastic recovery) of the centre of the land is greater, and this results in the slight taper shown here as angle delta. Although this taper is shown as a straight line, in practice the contour is curved and the angles blend into one another.

This slight taper on the upstream side of the land increses the load carrying capacity of the bearing by inducing a large hydro-dynamic oil pressure. The corresponding taper on the downstream side of the land (being in the reverse direction) is not able to contribute greatly towards the hydro-dynamic oil pressure and hence towards the load carrying capacity of the land and hence the load carrying capacity of the bearing.

Turning now to Figures 8 and 9 there is illustrated therein details of a uni-directional bearing wherein the troughs and ridges may be advantageously asymmetrical.

Figure 8 shows a section of a typical contour of the sintered bearing surface (generated into a straight line for ease of illustration) produced from a forming core rod which has a similar but reverse contour. The contour has two angles shown as alpha and beta wherein angle alpha is defined as in the same direction as the shaft rotation and angle beta is defined in the opposite direction to the shaft rotation; the distinguishing feature being that angle alpha is less than angle beta. The direction of shaft rotation is shown by the arrow.

Figure 9 shows a section through the same contour of the sintered bearing of Figure 8 after the bearing bore has been sized with a smooth surface core rod in the coining tools, such as for example of the type shown in Figure 4. It should be noted that the tops of the ridges have been flattened by the action of the sizing core rod whilst the angles alpha and beta leading up to and away from the flattened tops remain almost unchanged.

Figure 9A shows a magnified view of the junction of the leading ramp (at angle alpha) to the flatted land. This flatted land produced by the coining action is not perfectly flat but has a small slope shown as angle delta. This small angle arises because the porous metal immediately below the top of the ridge has undergone more plastic deformation than the porous metal away from the top of the ridge and has therefore been subjected to a higher stress (to achieve the higher strain) than the porous metal away from the top of the rib. Upon the removal of the sizing core rod, those areas which have been subjected to the higher stresses spring back more than the areas which have been subjected to the lower stresses. This differential in the amount of springback results in a slight taper at the leading edge of the flatted land shown as angle delta in Figure 9A. This slight taper is important in the production of a large hydro-dynamic oil pressure across the face of the flattened tops of the ridges which increases the load carrying capacity of the lands and hence of the porous bearing as a whole.

As hereinbefore described the bearing is in the form of a hollow cylinder having an inner cylindrical bearing surface but it will be appreciated that other shapes of bearing may be made in accordance with the invention. Thus a self aligning bearing may be produced having a part spherical outer surface and an inner cylindrical bearing surface; the shape of the outer surface being produced by appropriate part spherical curvature on the forming tools and coining tools.

Furthermore a bearing may be produced having an inner cylindrical bearing surface but also having one or both ends adapted as a thrust bearing surface. Such thrust surface may comprise the actual end wall of the bearing or, more usually, will comprise a flange at the end of the bearing. The thrust bearing surface comprises the axially outer surface of the flange and may be formed with generally radially extending troughs and ridges produced either by the forming tools or by the coining tools. In such a construction the angle and cross-sectional configuration of the troughs and ridges on the flange bearing surface may be chosen so as to provide a multi-directional or uni-directional thrust bearing surface. Also such surface may be provided with a "herringbone" pattern of troughs and ridges which again may be produced by either the forming tools or the coining tools.

Also a bearing in accordance with the invention may be adapted for uni-directional loading on its inner cylindrical bearing surface in which case it may only be necessary to impress the alternating troughs and ridges over, for example, a 120° arc of the bearing surface, which arc comprises the actual load bearing area of the bearing.

It will be appreciated that the provision of a bearing surface having troughs and ridges in accordance with the invention will give rise to improved bearing performance in use since the apices of the ridges i.e. the radially innermost portions of the bearing surface will constitute load carrying land areas and the bottoms of the troughs will constitute an "oil dam" forming region whereby the "ramp" between the bottoms and the apices of the troughs and ridges will provide the tapering region necessary for hydro-dynamic lubrication of the lands during rotation of a journal within the bearing.

It is to be understood that by the use of the term "oil" herein we mean both ordinary lubricating oils and also any other lubricating substance with can be impregnated into the porous bearing.

Claims

1. An oil impregnated sintered porous metal bearing having a bearing surface comprising a plurality of alternating troughs and ridges circumferentially spaced around the bearing surface and extending parallel to one another and to the longitudinal axis of the bearing.

2. A bearing as claimed in Claim 1 wherein the alternating troughs and ridges provide a bearing surface of the bearing which is of generally sinusoidal cross-sectional configuration as hereinbefore defined.

3. A method of manufacturing a bearing as claimed in Claim 1 comprising the steps of forming a green compact of metal powders in forming tools; sintering the green compact by heating it in an atmosphere which is reducing to the oxides of the metal powders; compressing the resulting sintered compact in coining tools to produce a coined bearing of the required final dimensions and impregnating the resulting porous bearing with a lubricating oil characterised in that the said alternating troughs and ridges are formed subsequent to the sintering of the compact.

4. A method according to Claim 3, wherein the troughs and ridges are formed by corresponding ridges and troughs on the coining tools.

5. A method according to Claim 3, wherein the troughs and ridges are formed by a further operation subsequent to the coining operation.

6. A method of manufacturing a bearing as claimed in Claim 1 comprising the steps of forming a green compact of metal powders in forming tools; sintering the green compact by heating it in an atmosphere which is reducing to the oxides of the metal powders; compressing the resulting sintered compact in coining cools to produce a coined bearing of the required final dimensions and impregnating the resulting porous bearing with a lubricating oil characterised in that the said alternating troughs and ridges are formed in the green compact by the forming tools.

7. A method according to Claim 6, wherein said troughs and ridges are subsequently reduced in depth during compression of the sintered compact in the coining tools.

8. A bearing according to Claim 1 or Claim 2 further comprising a thrust bearing surface formed with generally radially extending ridges and troughs.

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